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U. S. Department of Agriculture

Issued December 4, 1909

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY—Circular No. 43.
B. T. GALLOWAY, Chief of Bureau.

THE DETERIORATION OF CORN IN STORAGE.

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THE DETERIORATION OF CORN IN STORAGE.^a

INTRODUCTION.

In February, 1909, special investigations were begun at Baltimore, Md., in cooperation with the Baltimore and Ohio Railroad Company, for the purpose of obtaining definite information regarding the deterioration of shelled corn in elevator bins and in grain cars. The first series of experiments in these investigations comprised tests with (1) 5,550 bushels of corn stored in a 65-foot elevator bin for 69 days, until the corn at the top of the bin had become badly damaged; (2) 900 bushels of dried damaged corn from the top of the bin loaded into car No. 67031 and held on the track for an additional 37 days, and (3) 900 bushels of the best cool corn from the same bin loaded into car No. 75197 and held on the track with the car containing the dried damaged corn.

In this preliminary report no attempt has been made to generalize the results of the experiments, to draw any definite conclusions, or even to give any extended expression of opinion. The aim has been to outline the conditions under which this first series of experiments was made and to give a brief summary of the results obtained, leaving the individual reader to formulate his own theories until the investigations are more advanced. It is hoped, however, that this preliminary report will provoke discussion and bring about a better understanding of the purpose and value of investigations of this character.

CORN STORED IN ELEVATOR BIN.

On February 17 and 18, 1909, 5,550 bushels of shelled corn were stored in a 65-foot bin ^b in elevator C of the Baltimore and Ohio Railroad Company at Baltimore (Locust Point), Md. This corn was left without "running" until April 27, 1909, at which time the fermentation at the top of the bin had progressed so that the corn was hot and sour, the temperature 8 inches below the surface having reached 133° F.

^a This opportunity is taken to acknowledge the cordial cooperation of the Baltimore and Ohio Railroad Company and the Baltimore Chamber of Commerce, through its grain-inspection department. Special thanks are due to the various men assigned for duty at the elevator, who willingly rendered every possible assistance while these experiments were in progress.—B. T. GALLOWAY, *Chief of Bureau*.

^b The bin in which the corn was stored is near the center of the outer row of bins on the east side of the elevator, the outer 6-inch wooden wall of the bin being built against the heavy brick construction of the elevator.

The corn used in these experiments was taken from cars selected from those received at Baltimore, Md., on February 16, 1909. So far as the records available show, 4,050 bushels of this corn were grown in the Dakotas, the remaining 1,500 bushels having originated in Illinois. The 3,050 bushels first run into the bin consisted of practically all Dakota corn. The next draft of 500 bushels was Illinois corn with a small admixture of Dakota corn. The 1,000 bushels following consisted of Illinois corn, while the 1,000 bushels in the tenth and eleventh drafts at the top of the bin were composed of corn from the Dakotas.

In filling the bin each draft consisted of 500 bushels, with the exception of the first 50 bushels at the bottom of the bin. After almost every draft, samples were taken with a 4-foot grain trier, one from the center and one from near each corner of the bin, and the different factors representing the quality and condition of the corn were determined for each sample. The average results of the analyses of the samples representing the different drafts are given in Table I. These results show the moisture content; weight per bushel; weight of 1,000 kernels; sound corn; damaged corn; other grains; weeds, cobs, etc.; badly broken corn; and germination of whole kernels. A comparison of Table I with figure 1 will show the exact location of the corn in the bin represented by each set of averages given in the table.

TABLE I.—Average condition and quality of the 5,550 bushels of corn at the beginning of the experiment, as shown by the analyses of samples taken with a 4-foot grain trier after the different drafts were emptied into the bin.^a

No. of draft.	Amount of draft.	Moisture content.	Weight per bushel.	Weight of 1,000 kernels.	Sound corn.	Damaged grains.	Other grains.	Weeds, cobs, dirt, etc.	Badly broken corn.	Germination of whole kernels.
	<i>Bus.</i>	<i>P. ct.</i>	<i>Lbs.</i>	<i>Grams.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
(Bottom).....	50	17.8	53.5	280	97.9	0.8	0.5	0.8	2.4	
1.....	500	17.9	53.8	294	97.6	1.0	.9	.5	3.1	
2.....	500	17.8	53.6	337	97.4	.5	1.2	.9	3.3	81.3
3.....	500	17.9	53.3	295	96.9	1.4	.9	.8	2.0	72.8
4.....	500	18.0	52.6	303	96.2	2.5	.4	.9	3.5	73.0
5.....	500	17.8	53.6	296	96.6	2.2	.4	.8	3.3	77.3
6.....	500	18.8	53.0	286	97.7	1.8	.1	.4	1.4	69.0
7.....	500	17.5	54.5	317	97.6	1.3	.5	.6	3.5	87.8
8 and 9.....	1 000	17.0	55.0	330	96.9	.7		2.4	5.4	95.0
10.....	500	18.6	53.3	272	96.3	1.4	1.1	1.2	3.9	71.8
11.....	500	18.3	52.8	276	96.6	1.6	.9	.9	3.7	73.0
Average.....		17.8	53.7	301	97.0	1.4	0.6	1.0	3.0	80.6

^a All figures in the table other than those in the first two columns represent averages, so that the final average of all the corn in the bin is based on a total of 43 samples, or 1 sample for approximately every 130 bushels of corn emptied into the bin.

As will be seen from the table, the average moisture content of the corn in the different drafts varied from 17 per cent in the eighth and ninth to 18.8 per cent in the sixth draft, with an average of 17.8 per cent for all of the corn in the bin. The weight per bushel

varied from 52.6 pounds in the fourth draft to 55 pounds in the eighth and ninth, with a total average of 53.7 pounds. Similar variations are shown in the other factors, most of which indicate that the corn of the highest quality and in the best condition was the Illinois corn contained in the eighth and ninth drafts.

NOTES ON THE TEMPERATURE AND THE CONDITION OF THE CORN
WHILE IN THE BIN.

The bin used in this experiment was previously equipped with thirteen electrical resistance thermometers, so that temperature records of the corn in various parts of the bin could be taken at any time during the course of the experiment. Thermometer No. 1 was about $3\frac{1}{2}$ feet from the bottom, near the center of the hopper. The other thermometers were distributed through the center of the corn, approximately $8\frac{1}{2}$ feet apart, except that in the corn near the top of the bin, where deterioration is most likely to begin, additional thermometers were placed at various points. Figure 1 shows the location of these thermometers, numbered from 1 to 7 and from *A* to *E*, inclusive. In this same diagram are also shown the number of bushels contained in each draft, the average moisture content and the weight per bushel of the corn in the various parts of the bin at the time of filling, the temperature of the corn immediately after the bin was filled, and the maximum temperature of the corn at the end of the experiment, which extended over a period of 69 days.

The temperature of the corn immediately after the bin was filled varied from 36° to 40° F. As the bin was being filled the atmosphere was clear and dry, the relative humidity being 48 per cent. The temperature of the air in the elevator varied from 36° to $39\frac{1}{2}^{\circ}$ F. While the corn was in storage, temperature readings were made every two or three days until April 22, when the corn at the top of the bin gave evidence of very rapid deterioration, necessitating frequent readings during the remaining five days of the test.

The first indication that the corn had begun to deteriorate was on the 26th of March, after it had been in storage 37 days, at which time a slightly sour odor was perceptible in the corn at the top of the bin, showing that fermentation had begun. The highest temperature recorded at this time was 42° F., by thermometer *C*, approximately 5 feet below the surface of the corn. From this time on the increase in the temperature of the 500 bushels of corn at the top of the bin became more pronounced. However, 27 days later, on April 22, the highest temperature recorded was still less than 70° F., but during the 5 days immediately following a maximum of 133° F. was reached, 8 inches below the surface of the grain.

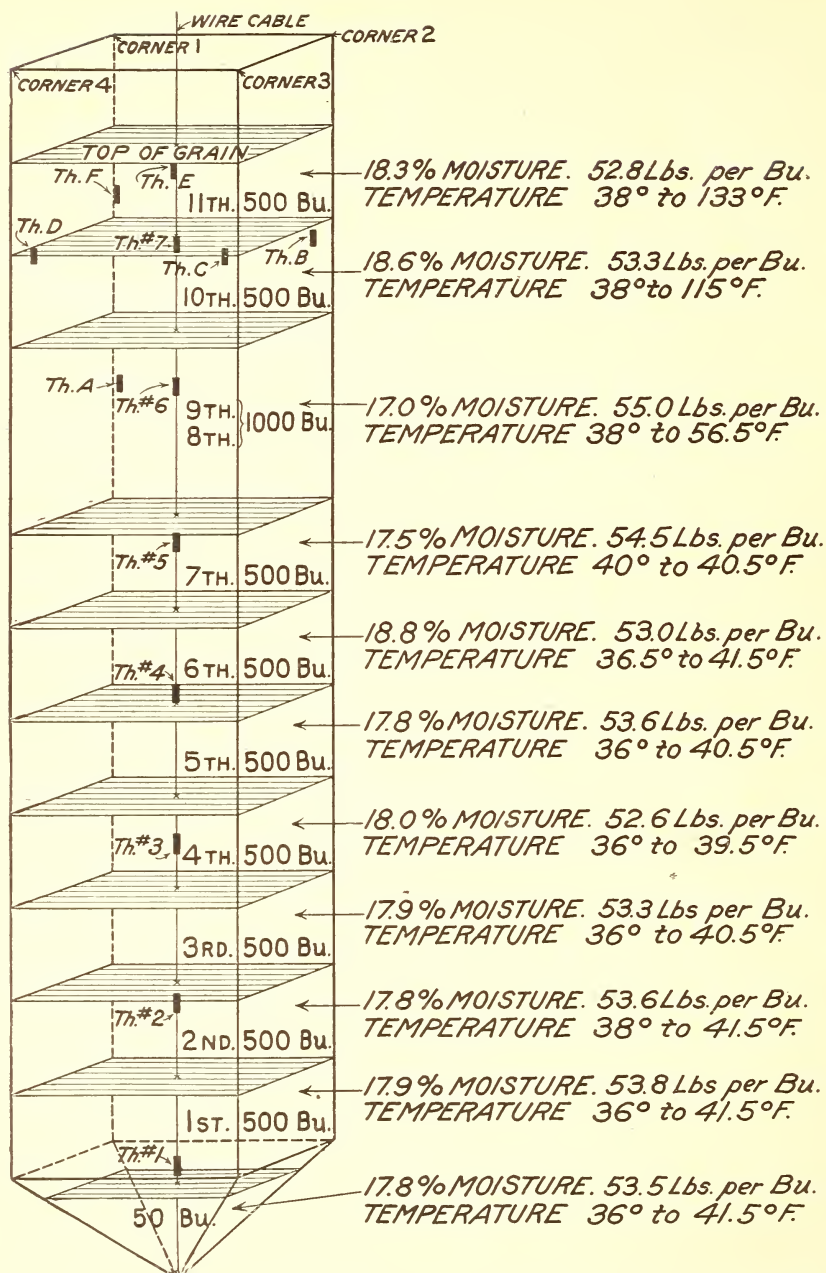


FIG. 1.—Diagram showing the position of the thermometers; the number of bushels, the moisture content, and the weight per bushel for each draft; and the temperature of the corn at the beginning and at the end of the experiment.

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On March 31 three holes were bored through the wall of the bin on the side nearest the interior of the house. One hole was bored approximately 10 feet from the bottom, another 25 feet from the bottom, and the third 40 feet from the bottom of the bin, or 20 feet from the top of the grain. Samples taken through these holes with a 4-foot grain trier showed that the corn had not changed materially since it was first placed in the bin, no unnatural odors being perceptible. On the same date samples taken with a long grain trier from 7 feet below the surface showed the corn at that point to be slightly musty.

Samples taken on April 3 from 3, 7, and 12 feet below the surface showed more pronounced odors in the corn at 3 and 7 feet, but no odor could be detected in the samples taken at 12 feet. At this time the maximum temperature of the corn 12 feet below the surface was 42° F. The highest temperature in the upper 500 bushels was 45½° F. On April 6 the corn near the top of the bin was very musty, although the maximum temperature was only 48° F. On April 13, samples were again taken from 12 feet below the surface but revealed no odors indicating deterioration.

On April 19 the maximum temperature in the 500 bushels of corn at the top of the bin was 61½° F., as registered by thermometer *E*, 8 inches below the surface. The corn near the top at this time was very musty and a considerable quantity of fresh mold was growing on the kernels. The temperature of the corn 12 feet below the surface, as registered by thermometer *A*, was 56° F., which was within one-half degree of the highest temperature recorded at that depth during the entire test.

On April 26, samples were again taken through the holes in the side of the bin at 10, 25, and 40 feet from the bottom, together with a number of samples representing the 1,000 bushels at the top of the bin. At this time the corn at the top of the bin was hot, musty, and sour, but no odor could be detected on the samples taken through the hole 10 feet from the bottom of the bin. However, the samples taken through the holes 25 and 40 feet from the bottom of the bin showed that the corn near the bin walls at those points was slightly sour. This condition was shown more clearly when the bin was emptied the following day, the corn having a tendency to adhere to the sides. In emptying the bin the corn from the sides became unevenly mixed with the better corn from the interior, so that an odor was perceptible on a considerable portion of the entire bulk.

The fermentation in the upper 500 bushels of corn was very active at this time and the temperature was increasing rapidly. On April 25 thermometer No. 7, in the center about 5 feet beneath the surface of the corn, registered 87° F. At 8 o'clock the following morning

this same thermometer registered 102° ; at 11.45 a. m., 105° ; at 3.10 p. m., 107° , and at 9 o'clock the morning of the 27th, 115° , an increase of 28 degrees F. in 48 hours. The highest temperature registered on April 27 was 133° F., in corner No. 4, 8 inches below the surface of the corn. In corner No. 1, 14 inches below the surface, the temperature was 110° ; in corner No. 2, 112° ; in corner No. 3, 125° ; and in corner No. 4, $132\frac{1}{2}^{\circ}$. Thermometer *B*, in corner No. 2, the same depth below the surface as thermometer No. 7, registered 71.5° F.

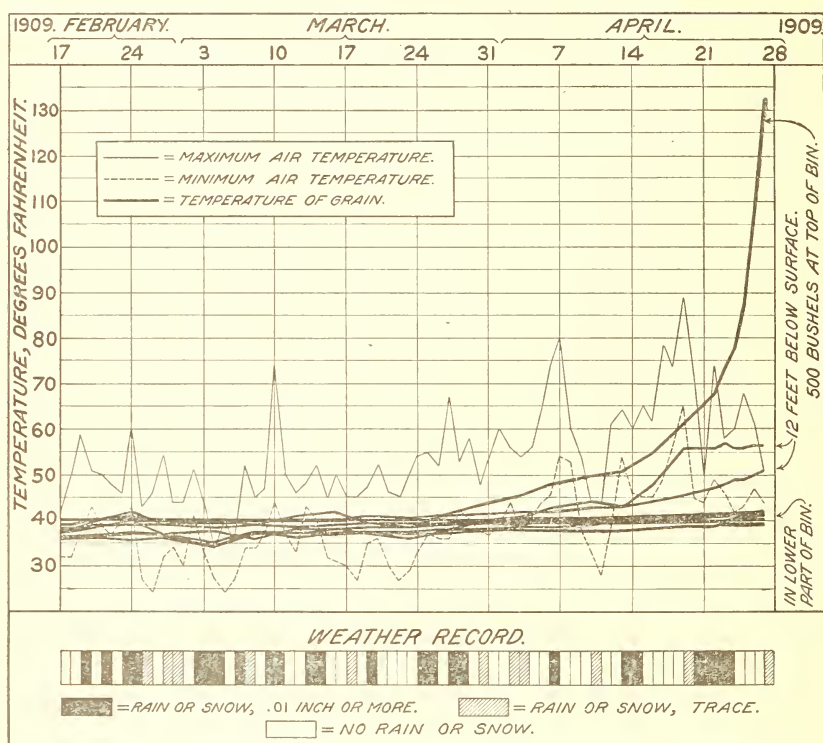


FIG. 2.—Diagram showing the temperature of the corn in various parts of the bin, the daily maximum and minimum air temperature, and the precipitation from February 17 to April 27, 1909.

A clearer understanding of these conditions will be had by consulting figure 2, which shows the temperature of the corn in various parts of the bin, together with the daily maximum and minimum air temperature, and the general character of the precipitation during the 69 days covered by the experiment.

CONDITION OF THE CORN AT THE END OF THE EXPERIMENT.

As shown in figure 2, the only marked increase in temperature was in the 6 or 7 feet of corn at the top of the bin. The maximum temperature registered by thermometers No. 6 and 4, approximately 12

feet below the surface, was 51° and $56\frac{1}{2}^{\circ}$ F., respectively. The temperature of the corn in the lower part of the bin varied from $39\frac{1}{2}^{\circ}$ to $41\frac{1}{2}^{\circ}$ F., as compared with a variation of from 36° to 40° F. at the beginning of the experiment.

The moisture content of the corn immediately at the surface was 14.95 per cent, or 3.35 per cent less than on February 17. The moisture content of the 1,000 bushels at the top of the bin, exclusive of the corn on the surface, was slightly higher than when the corn was placed in the bin, showing that the deterioration of the corn was resulting in the formation of more water than was being given off by evaporation. The weight per bushel of the surface corn was 54 pounds, while the weight of the remainder of the upper 1,000 bushels had decreased from 53 to 51 pounds.

The germination of the poorest corn from the top of the bin varied from 0 to 17 per cent, with an average of 10.3 per cent, as compared with an average of 72.4 per cent on February 17. This corn was damaged so that many of the germs were badly discolored. The average germination of the 1,070 bushels taken from the top of the bin for further experiment, which included not only the hot corn but all that had a temperature over 50° F., was 42.6 per cent after being handled, dried, and loaded into car No. 67031.

The corn in the lower 45 feet of the bin, except 900 bushels of the best quality which was loaded into car No. 75197 for further test, after being handled over three elevators and dried to 14.87 per cent of moisture, was given a grade of "Mixed corn." The germination of this corn was 80.8 per cent at the beginning of the experiment, 71.4 per cent when drawn from the bin, and 81.4 per cent after being handled and dried.

The total loss in weight, as shown by the certificates furnished by the weighman of the Chamber of Commerce, resulting from filling and emptying the bin and the evaporation during the 69 days in storage, amounted to 310 pounds, or slightly less than one-tenth of 1 per cent.

DRIED DAMAGED CORN FROM TOP OF BIN STORED IN CAR.

The 1,070 bushels of corn drawn from the top of the bin was weighed, handled over three elevators, and reweighed, after which it was artificially dried in a grain drier at a temperature varying from 151° to 163° F. The average moisture content of this corn as taken from the bin was 18.64 per cent. The average moisture content when emptied into the drier was 18.30 per cent, or a reduction of 0.34 of 1 per cent as a result of the handling, which is equivalent to a loss in weight of 0.4 of 1 per cent.^a In drying, the moisture con-

^a Circular 32, Bureau of Plant Industry, U. S. Dept. of Agriculture, entitled "Moisture Content and Shrinkage in Grain," explains why this difference exists and how it is calculated.

tent was reduced from 18.3 per cent to 14.57 per cent, a reduction of 3.73 per cent, which is equivalent to a loss in weight of 4.44 per cent.

After this corn was dried and thoroughly cooled, 900 bushels, having an average moisture content of 14.57 per cent, were loaded into car No. 67031 as if intended for shipment. The car was run out into the yard and left standing on the track fully exposed to all atmospheric changes. The temperature of this corn immediately after it was loaded into the car, after drying and cooling, on April 27, varied from 57° to 58° F. Frequent temperature readings were made up to and including May 25, when the highest temperature at any point in the corn was 66° F., an increase of only 8 or 9 degrees, although the temperature of the air in the car had varied from 56° to 82° F. and the temperature of the air outside of the car from 41° to 90° F. On May 25, after being in the car 28 days without any noticeable change in condition, the corn was unloaded, elevated, and weighed, and then returned to the car and left an additional 9 days on the track. The air temperature at this time was 73° F., resulting in a very slight increase in the temperature of the corn by the time it was returned to the car.

On June 3 the temperature of the corn was 67° F., an increase of only 10 degrees during the entire 37 days that this corn was in the car. The condition of the corn was fully as good if not better than when it was placed in the car on April 27, although the odor resulting from the fermentation of the corn while in the bin had not entirely disappeared.

On June 3 the moisture content of the corn on the surface was 13.1 per cent, with 14.48 per cent for the remainder of the corn in the car, a difference of 1.38 per cent in the moisture content, which is equivalent to a shrinkage in weight in the surface corn of 1.59 per cent in 9 days from May 25 to June 3.

UNDRIED CORN FROM BIN STORED IN CAR.

In order to secure data for comparison, 900 bushels of the best cool corn from the bin, principally the Illinois corn from the eighth and ninth drafts, were loaded into car No. 75197 and placed on the track alongside of the car containing the 900 bushels of dried damaged corn from the top of the bin. The temperature of this corn while still in the bin varied from 40° to 42° F., but in "running" from the bin, elevating to the scale, and loading into the car, the temperature was increased so that the temperature of the corn after being loaded was 48° F. The air temperature at this time was 51° F. and the relative humidity of the atmosphere 76 per cent. The average moisture content of this car of corn was 17.5 per cent, and the weight per bushel was 55.3 pounds.

On May 20, after standing on the track 23 days, the corn in this car began to show unmistakable signs of deterioration. At that time the maximum temperature of the corn was 75° F., and it had a distinctly sour and musty odor. Five days later the maximum temperature was 122° F. in the brake end of the car, approximately 6 inches below the surface of the corn. The average weight per bushel had decreased from 55.3 pounds to 52.6 pounds. The moisture content varied from 13.6 per cent in the corn at the surface to 17.5 per cent where the temperature was 122° F., as compared with a variation of from 17 per cent to 17.7 per cent at the time the corn was loaded into the car.

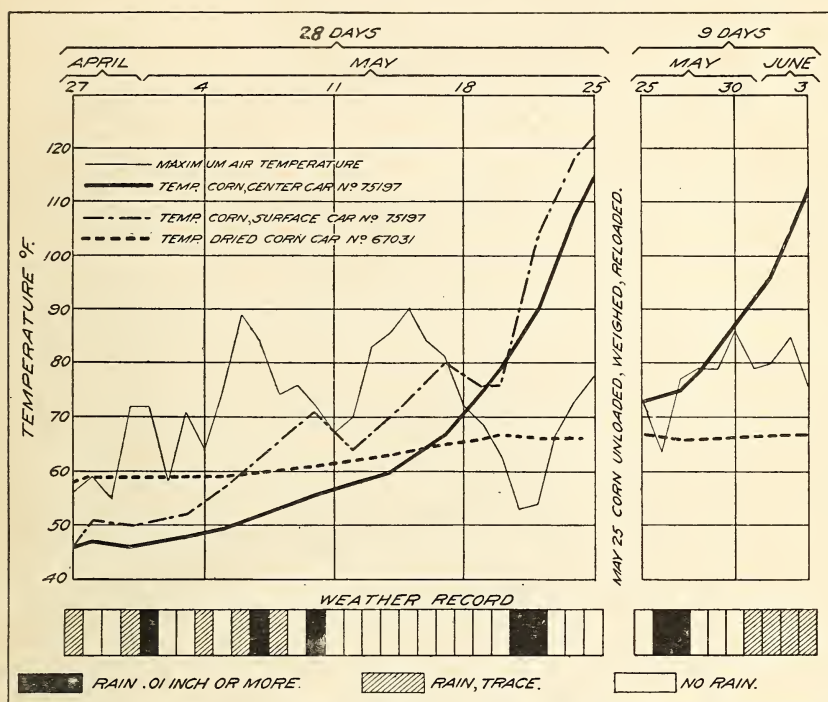


FIG. 3.—Diagram showing the temperature of the undried corn in car No. 75197 and of the dried damaged corn in car No. 67031; the daily maximum air temperature; and the weather record from April 27 to June 3, 1909, while these cars were on the track in the Baltimore and Ohio elevator yards.

On May 25 this corn was unloaded, weighed, handled over five elevators, reweighed, screened, weighed a third time, and returned to the car for further observation. When the corn was returned to the car the second time (May 25) the temperature was 73° F., approximately the same as the temperature of the air at the time the corn was handled. On June 3, 9 days later, the corn in this car was again hot, the maximum temperature being 112° F., showing that hot corn is not made safe for shipment when cooled simply by handling.

Figure 3 shows the changes in temperature in both the car of undried corn and the car of dried damaged corn while on the track

from April 27 to May 25 and from May 25 to June 3, together with the daily maximum air temperature and the weather record for the same period. The diagram also shows that only the corn near the surface was influenced by the temperature of the outside air.

LOSS IN MOISTURE AND SHRINKAGE.

When the undried corn from the bin was first loaded into car No. 75197, on April 27, the average moisture content was 17.47 per cent. On May 25, when the maximum temperature of the corn was 122° F., the average moisture content of the surface corn was 13.55 per cent. Samples taken from 5 inches below the surface showed a moisture content of 17 per cent. The highest moisture content found was 17.5 per cent, in samples taken at the point where the temperature was 122° F.

The shrinkage in weight in the layer of corn at the surface, based on the reduction in moisture of 3.92 per cent, was 4.53 per cent. On May 25 this corn was unloaded and reweighed by the weighman of the Chamber of Commerce on the scales regularly used at the elevator. The loss in weight in the loading and unloading and through evaporation while in the car from April 27 to May 25 was 367 pounds, or 0.728 of 1 per cent. This corn was then handled over five elevators, screened, weighed, and reloaded. In this handling and reloading the moisture content was reduced to 16.55 per cent, or 0.92 of 1 per cent less than when the corn was first loaded into the car on April 27, which is equivalent to a loss in weight of 1.1 per cent due to the evaporation of moisture while in the car and in the handling of the hot corn in the elevator. On June 3, this car of corn, cooled by handling, was again hot, the temperature having increased from 73° F. to 112° F. from May 25 to June 3. The average moisture content of the surface corn was only 13.95 per cent, as compared with 16.55 per cent when reloaded, a reduction in moisture of 2.6 per cent in 9 days.

The low moisture content of the surface corn showed that water was being lost by evaporation and that this evaporation is quite rapid when the temperature of the corn is relatively high. It must be remembered, however, that this car was opened frequently and the corn on the surface more or less disturbed in the securing of samples, in reading temperatures, etc., so that the same results might not apply in the same degree to corn in transit where the cars are unopened from point of shipment to destination.

Approved:

JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., November 5, 1909.

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